

A STUDY OF WIRELESS LTE INFRASTRUCTURE GROWTH IN THE
MATANUSKA-SUSITNA BOUROUGH

By

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Abstract

A wireless telecommunications company is targeting to have seamless coverage and minimum download speeds of 10Mbps for users connected to their LTE network over the span of the next 3 years in the Matanuska-Susitna area. The current network performance was explored and it was determined to have non-contiguous coverage with average download speeds of 5.876Mbps, not meeting the requirements. To meet the requirements, techniques for coverage and capacity improvement were explored. Coverage improvement techniques include new base stations, adding lower band spectrum, and using antenna-integrated RRH. Capacity improvement techniques include new base stations, adding additional spectrum, and LTE enhancement features. The wireless telecommunications company is licensed to operate in PCS A/B/E blocks, AWS B block, and 700MHz A block for a total of 51MHz bandwidth. Recommendations based on the requirements and techniques to improve both coverage and capacity are listed below.

1. Add five new base stations with existing 10MHz bandwidth of AWS, 5MHz bandwidth of 700MHz spectrum, 20MHz bandwidth of PCS spectrum, and antenna-integrated RRH
2. Add 5MHz bandwidth of 700MHz spectrum, 20MHz bandwidth of PCS spectrum, and antenna-integrated RRH to existing base stations
3. Enable LTE-Advanced features including carrier aggregation and 4x4 MIMO to improve data rates

This solution will provide seamless coverage and expand data volume capacity from 155.751 TBytes to 601.910 TBytes per month allowing data rates to be above 10Mbps until the end of December 2021, after the three year requirement. Implementing the recommendations will allow the wireless telecommunications company to meet and slightly exceed requirements of seamless coverage and minimum download speeds of 10Mbps in the Matanuska-Susitna area.

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Introduction

A wireless telecommunications company is targeting to have seamless coverage and minimum download speeds of 10Mbps for users connected to their LTE network over the span of the next 3 years in the Matanuska-Susitna area. This target is critical to compete with other wireless carriers and to provide subscribers with uninterrupted service and to increase user experience throughout the area. Several aspects will be explored to determine if the requirements are being met today, if network expansion is required, and what is necessary to meet or exceed the requirements. This paper will answer the following questions. How is the wireless telecommunications company's LTE Wireless network performing today and are upgrades necessary? Given the predicted and estimated trends, how will the network perform in three years? If network expansion is necessary, what is the best solution to meet the requirements seamless coverage and a minimum data rate of 10Mbps? Are there any limitations for network growth? Are there potential future technologies that may assist in improving network speeds? Pseudo data will be created and will be used to determine current network performance, forecasting of network performance, and network expansion forecasting. Coverage and capacity techniques will be explored to determine solutions for network expansion. This paper will explore the wireless telecommunications company's LTE wireless network in the Matanuska-Susitna Borough and provide network expansion recommendations and forecasting to meet the requirements of seamless coverage and minimum download speeds of 10Mbps.

Wireless LTE Overview

Introduction of LTE

Wireless LTE, Long Term Evolution, is the fourth generation of mobile wireless communications technology that was introduced in 2008 to provide major improvements to data rates,

delay, and capacity compared to third generation technology using advancements in wireless technology (Nohrborg, n.d.). Similarly, to third generation wireless technology, LTE continues to use base stations to transmit and receive signals in the radio spectrum to provide coverage and capacity to users around the base station. However, with advancements in signal transmission, spectrum flexibility or variable bandwidth, spectral efficiencies, multiple antenna techniques, improved handling of interference, and many other improvements, a peak theoretical data rate of up to 300Mbps can be achieved (Dahlman, Parkvall, & Sköld, 2014). Further improvements to LTE, with the focus on even higher capacity and data rates, introduced LTE-Advanced with functionalities including Carrier Aggregation, advanced multi-antenna techniques, support for relay nodes, and Coordinated Multi-Point operation (CoMP). With a mobile device that is compatible with LTE-Advanced, peak theoretical data rates can be up to 3Gbps (Wannstrom, 2013). With all of the advancements in LTE, wireless mobile network operators can determine if one or more of these advancements are necessary or possible to be implemented in their network to improve data rates and provide additional capacity for subscribers using their LTE network.

LTE Coverage and Capacity

Wireless LTE coverage and capacity is critical for users to connect to LTE and to achieve high data rates (Dahlman, Parkvall, & Sköld, 2014). Theoretical maximum data rates can be calculated using signal power, noise power, and bandwidth, where bandwidth is the amount of spectrum of the channel, signal power is the average received signal power over the bandwidth, and noise power is the average power of noise and interference over the bandwidth. Coverage analysis will include signal power and noise power and capacity analysis will also include bandwidth, which are all limiting factors for theoretical maximum data rates based on Shannon's Theorem for theoretical channel capacity given by the simple expression in Eq. 1.

$$C = BW \times \log_2\left(1 + \frac{S}{N}\right) \quad (1)$$

where C is the maximum channel capacity in bits per second, BW is the bandwidth in hertz, S is the signal power in watts, and N is the noise power in watts. Theoretical maximum data rate cannot exceed channel capacity. The ratio of S/N is commonly referred to as SNR (signal-to-noise ratio) or SINR (signal-to-interference-plus-noise ratio) if interference exists. Theoretical maximum data rates using Shannon's Theorem is shown in Figure 1: Shannon's Theorem Theoretical Channel Capacity for Different Bandwidths for Increasing SNR.

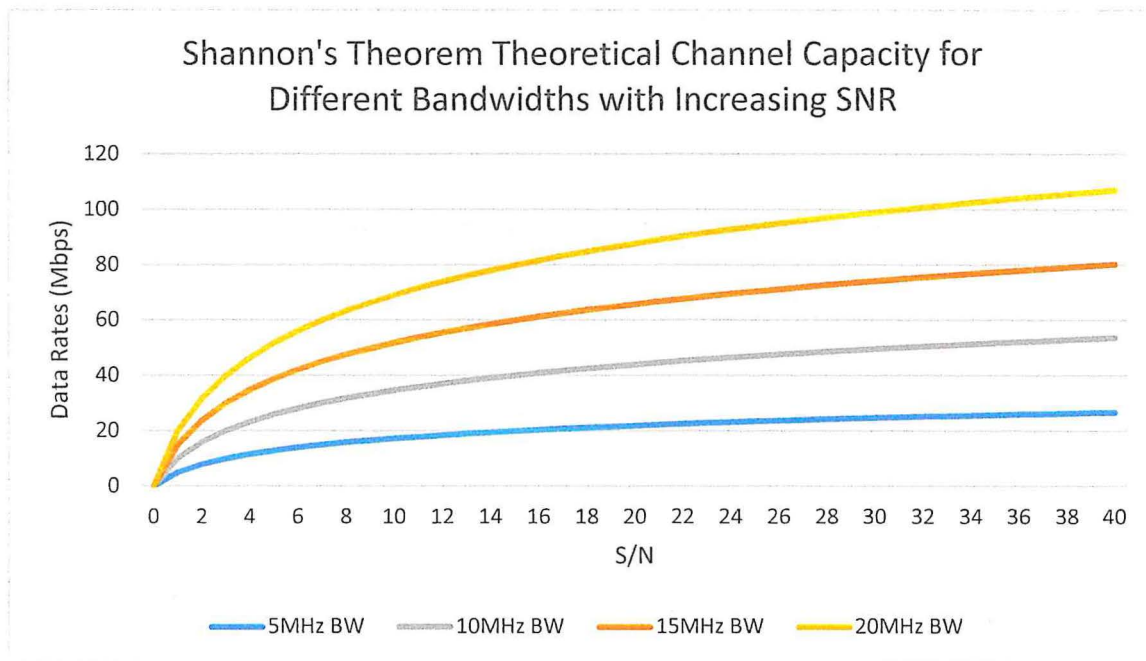


Figure 1: Shannon's Theorem Theoretical Channel Capacity for Different Bandwidths for Increasing SNR

Based on Shannon's Theorem, a static bandwidth with changes in only signal power and noise power will increase or decrease the data rates and by increasing only the bandwidth, data rates increase at a much higher rate. An illustration was created to show devices with a high and low signal power and low

noise area that would affect data rates, shown in Figure 2: Illustration of relationship between SNR and data rates.

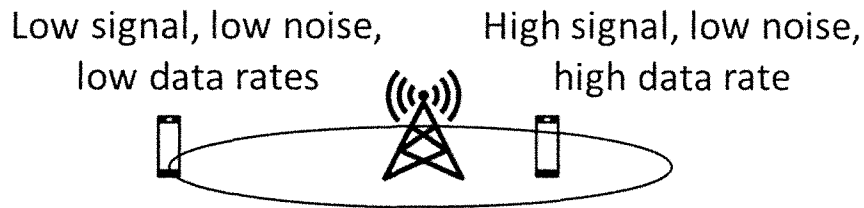


Figure 2: Illustration of relationship between SNR and data rates

When SNR is high or low, data rates theoretical would be high and low respectively. Analysis of SNR will show areas of low data rates which can be identified and improved. Overall network capacity and data rates can also be improved by increasing bandwidth. These aspects will be identified and forecasted with solutions that can be implemented in the wireless telecommunications company's LTE network.

Current LTE Coverage and Performance

Current LTE Coverage

A wireless telecommunications company's wireless LTE network currently consists of forty-eight base stations spread throughout the lower Matanuska-Susitna Borough. Each base station provides wireless LTE coverage and capacity within a certain distance of the base station dictated by multiple factors which will not be discussed. This section will focus only on coverage, or signal power and noise power. Wireless coverage can be determined using a few different methods including wireless pathloss prediction or drive test (Obot, Simeon, & Afolayan, 2011). Propagation prediction uses software tools with user provided inputs to estimate the wireless coverage. This method is typically used in the design phase as the actual coverage cannot be determined as the infrastructure does not exist. A drive test

uses mobile wireless phones to measure the actual coverage of an operational system. This method is typically used in the testing or optimization phase to determine the actual coverage. Since the wireless telecommunications company's LTE network is operational in the Matanuska-Susitna Borough, this method was chosen to determine current wireless LTE coverage. Using the drive test method to determine coverage, majority of the areas in the Matanuska-Susitna Borough were driven to collect data using multiple mobile wireless phones. These phones are loaded with an application that continuously measures network signals and location data. Once the data is collected, it is plotted on mapping software. A subset of this data that will be used includes signal power (RSRP) and signal-to-interference-plus-noise-ratio (SINR). RSRP will show areas where wireless signal exists and SINR will show areas of wireless signal and high noise areas. Users with low SINR, or low signal, high noise, or both, will experience low throughputs as the signal quality is poor (Deniz, Uyan, & Gungor, 2018). Poor SINR value of 5.6dB was chosen where throughput degrades lower than 10Mbps (Afroz, Subramanian, Heidary, Sandrasegaran, & Ahmed, 2015). Using this value, poor SINR areas in the Matanuska-Susitna Borough can be identified and is shown in Figure 3: The wireless telecommunications company's LTE Wireless network SINR in the Matanuska-Susitna Borough below plotted in the mapping software.

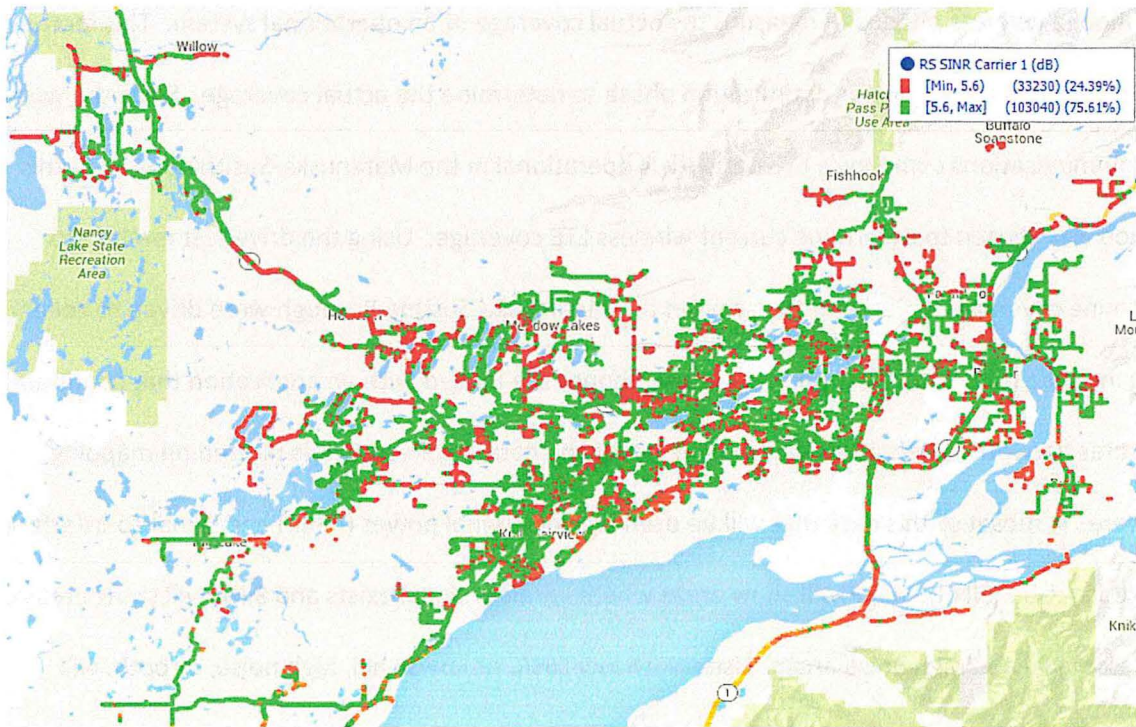


Figure 3: The wireless telecommunications company's LTE wireless network SINR in the Matanuska-Susitna Borough

The plot shows areas of poor SINR less than 5.6dB in red which may be contributed by poor signal power or high noise, and areas of good SINR greater than 5.6dB in green. To further identify if the contributor is signal power or noise, RSRP must also be plotted. A comparison with RSRP to closely match the SINR value of 5.6dB resulted in a signal power of -114dBm to determine if signal power or noise is the contributor of low SINR, shown in Figure 4: The wireless telecommunications company's LTE wireless network RSRP in the Matanuska-Susitna Borough.

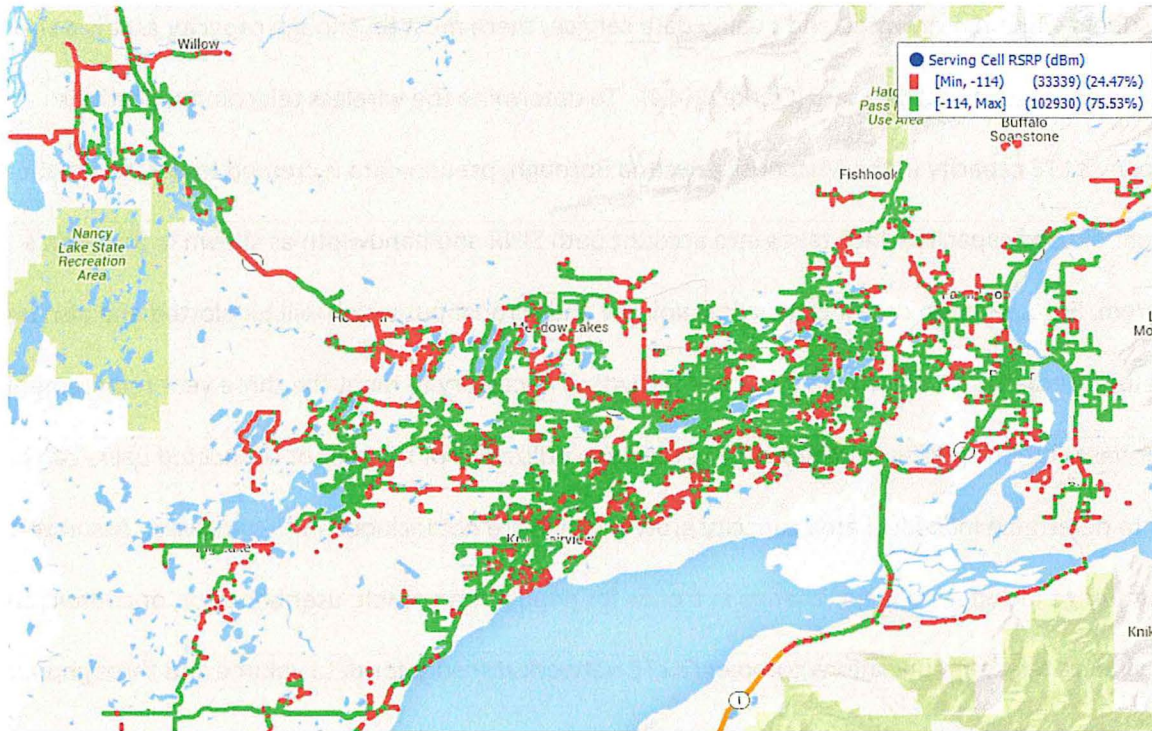


Figure 4: The wireless telecommunications company's LTE wireless network RSRP in the Matanuska-Susitna Borough

This shows areas of signal power less than -114dBm in red and greater than -114dBm in green. In areas that have signal power greater than -114dBm and SINR less than 5.6dB, we can assume that noise is the contributor. In areas that have signal power less than -114dBm and SINR less than 5.6dB, we can assume that signal power is the contributor. By comparing the two plots, areas with poor SINR also have poor signal power. Therefore, signal power is the main contributor in most areas, which will be candidates for signal power improvement. The current LTE network requires expansion as it currently does not meet the requirements for seamless coverage. Techniques for coverage signal power improvement will be discussed in a later section.

Current LTE Capacity

Wireless LTE capacity dictates subscriber's experience when transferring data on mobile devices and is defined as the maximum amount of data that can be transferred to subscribers. To provide

subscribers with uninterrupted and quality data service, there must be enough capacity as it is a shared resource amongst all active users (Clarke, 2014). To determine the wireless telecommunications company's LTE capacity in the Matanuska-Susitna Borough, pseudo data is created to determine the amount of used capacity which takes into account both SINR and bandwidth as shown in Shannon's Theorem, Eq. 1. Pseudo data includes data volume and throughput which will be plotted and also be used for forecasting to determine if network growth is necessary to meet the three year requirement. Other base station specific statistics such as resource utilization or number of connected users can be used to determine individual area capacity growth which are not included in this analysis. Assumptions in data usage includes no major change in trends for population growth, user behavior, or content size. The wireless telecommunications company's LTE network statistics for data volume and throughput is created from July 2015 to September 2018 shown in Figure 5: LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps).

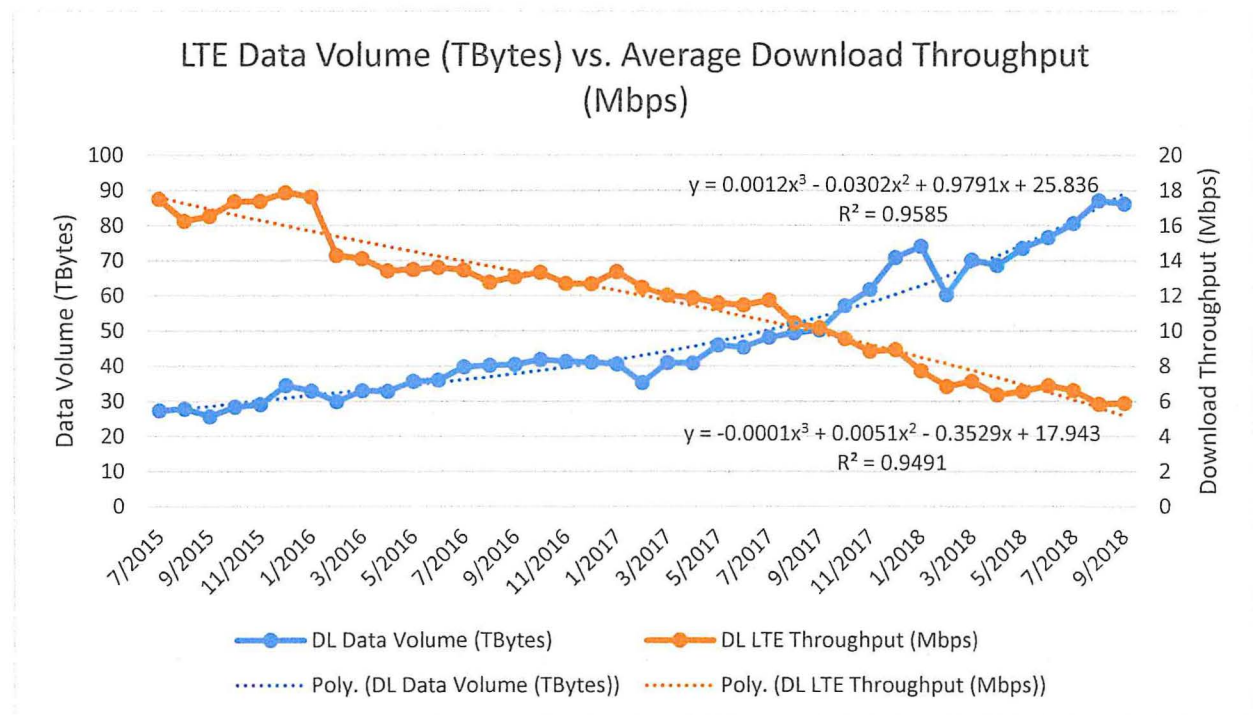


Figure 5: LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps)

The wireless telecommunications company's LTE data volume continues to grow as shown in the above Figure 5: Matanuska-Susitna Borough LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps), starting at about 30 terabytes in July of 2015 to almost three times that of 90 terabytes in September of 2018. LTE download throughput continues to decrease, starting at about 18Mbps in July of 2015 to almost a third of that to 6Mbps in September of 2018. From observation, this graph shows that as more data traverses the network, throughput decreases and is indirectly proportional. A third order polynomial best fit trend line was added for forecasting data volume and download throughput. The current LTE network requires expansion as it currently does not meet the requirements of a minimum of 10Mbps. Capacity growth techniques will be discussed in a later section.

Matanuska-Susitna Borough Population Growth

Population growth in the Matanuska-Susitna Borough was explored to determine if the population growth trend was consistent for the time the data was collected in the previous section. High variability in population growth may have caused fluctuations in data volume and data throughput as the number of active users share the same radio resources (Salo & Zacaías, 2017). If the forecasted population in the area increases or decreases significantly, the data volume would increase or decrease at a higher rate, which would also affect data throughput. Forecasted data volume and download throughput would need to adjust for non-linear population trends. If estimated population is linear, forecast models would continue the trend and not need to be adjusted for population. Limiting the variables will provide better forecasting models and network expansion recommendations. The population in the Matanuska-Susitna Borough is estimated by the United States Census Bureau and Alaska Department of Labor and Workforce Development which is graphed in the below Figure 6: United States Census Bureau and Alaska Population Projections estimate for the Matanuska-Susitna Borough.

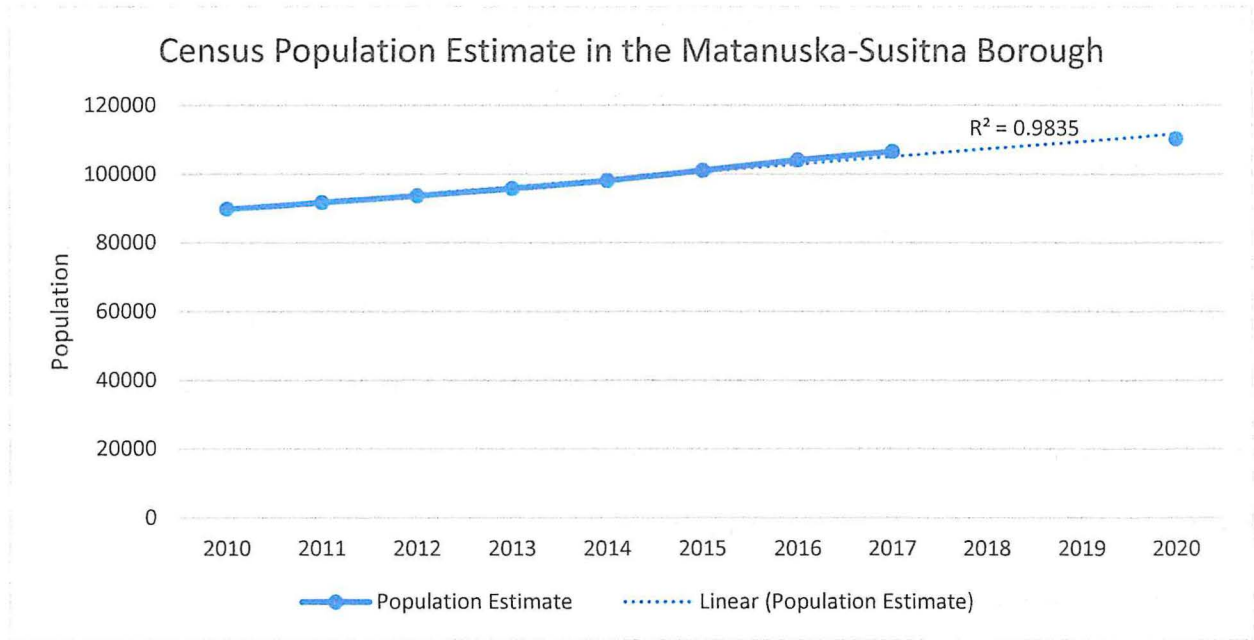


Figure 6: United States Census Bureau and Alaska Population Projections estimate for the Matanuska-Susitna Borough

As can be seen in the above Figure 6: United States Census Bureau and Alaska Population Projections estimate for the Matanuska-Susitna Borough, population growth estimate is almost linear and closely correlated with the trend line with a R^2 value of 0.9835. This shows that population growth is consistent with low population variability and that the forecasted model does not need to consider population growth as this is already assumed in the LTE data usage statistics.

Forecast Model of LTE Data Volume and Average Download Throughput

LTE data volume and average download throughput needs to be forecasted to determine growth requirements. A forecast of LTE data volume and average download throughput can be determined using the third order polynomial best-fit line and function from the data collected between July 2015 and September 2018, shown in Eq. 2 and Eq. 3.

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836 \quad (2)$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 \quad (3)$$

This assumes that SINR and bandwidth does not change. This also assumes the growth trend follows the pattern since July of 2015 to September of 2018 which includes population growth, consumer usage behavior, content size growth, and other factors. Using this function with X equal to months, the graph in Figure 7: Forecasted LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps) can be created.

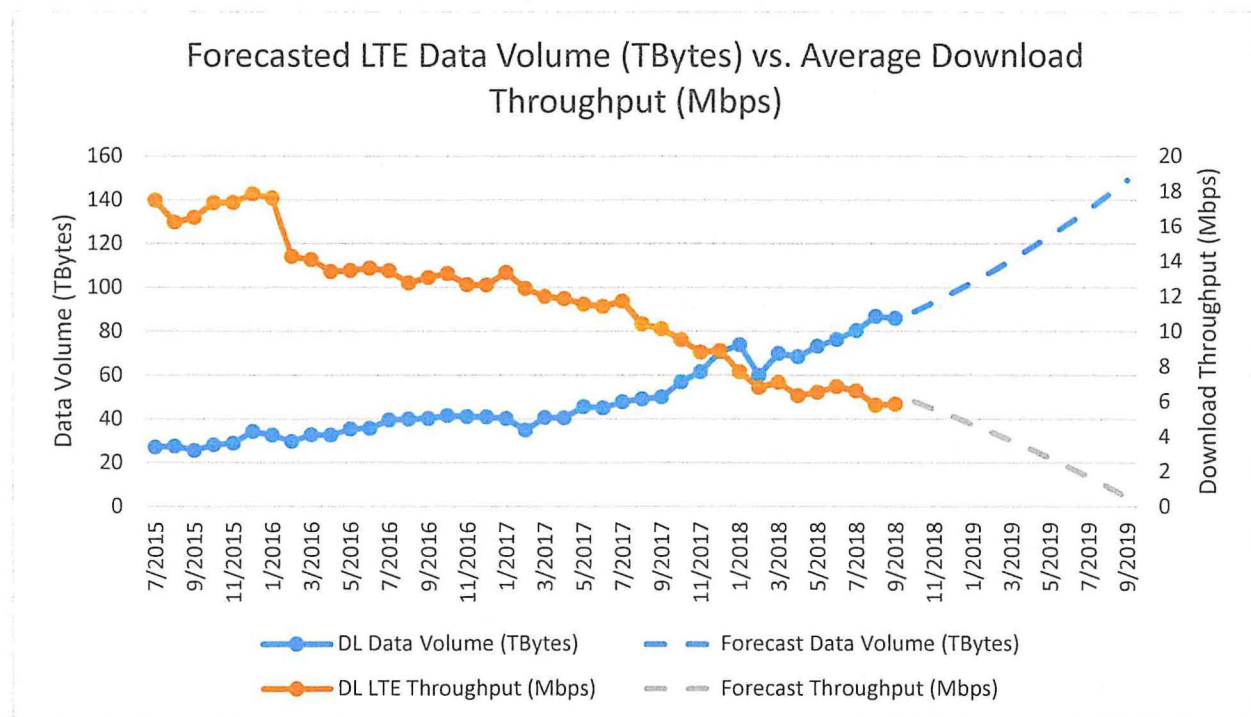


Figure 7: Forecasted LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps)

Forecasted data is shown as the dashed line after September of 2018. The graph shows LTE data volume continues an upward trend and LTE download throughput continues a downward trend. Forecasted LTE data volume and average download throughput in September of 2019, using the current infrastructure, will reach about 150 terabytes and 0.5 Megabits per second respectively. According to information from Netflix, required speeds to stream movies is 0.5 Megabits per second but recommended is 1.5 Megabits per second (Netflix, n.d.). After September of 2019, users would be

unable to stream movies to their mobile devices if network capacity is not increased in the Matanuska-Susitna Borough. Additionally, requirements for a minimum of 10Mbps are currently not being met. Network capacity growth is required as soon as possible prior to September 2019. Techniques for capacity growth will be discussed in the next section.

Network Growth Techniques

Techniques for Wireless LTE Coverage Improvement

Wireless LTE coverage of signal power can be improved using multiple techniques to provide seamless coverage. This includes deployment of new base stations, deployment of lower frequency spectrum, and deployment of antenna-integrated RRH (remote radio head). Each of these techniques has an associated cost, advantages and disadvantages, and may provide major or minimal coverage improvements that will be discussed in this section.

Deployment of new base stations can be a major contributor to improving coverage. Base station types can be divided into categories of typical coverage distances to include macrocells, microcells, picocells, or femtocells (Harris, 2011). An illustration of the categories is shown in Figure 8: Illustration depicting types of wireless base stations. This is not drawn to scale.

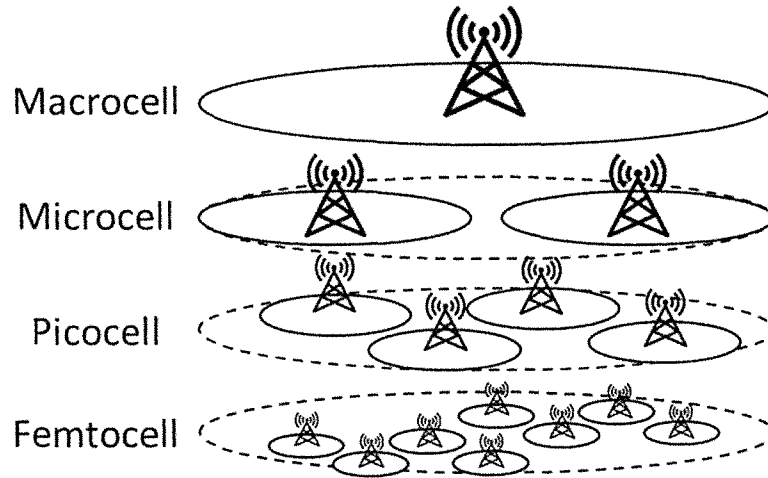


Figure 8: Illustration depicting types of wireless base stations

The illustration shows, from largest to smallest types of base stations that macrocells provide the largest area of coverage down to femtocells that provide only localized coverage. Depending on how much coverage is needed, base station type can be chosen. However, there is an associated cost with each type of base station. More detail is shown in Table 1: Types of Base Stations.

Table 1: Types of Base Stations

Base Station	Typical coverage distance	Coverage areas	Cost
Macrocell	10 miles	Rural/Suburban	High
Microcell	1 mile	Urban/Suburban	High/Medium
Picocell	250 yards	Office Buildings, airports, shopping malls, campuses	Medium/Low
Femtocell	In building	Personal device, home/office	Low

However, macrocells and microcells can be extremely costly as it requires large infrastructure such as a tower or building, antennas, base stations equipment, and supporting network infrastructure. Other factors that may affect additional macrocell and microcell base stations include physical access, electrical power and telecommunications network infrastructure, local zoning ordinances, environmental and wildlife impacts, architectural historic preservation, and aviation requirements

(Harris, 2011). If only localized coverage improvement is needed, lower cost options such as picocells and femtocells can be used.

Implementing lower band frequency spectrum can also significantly improve coverage, depending on the terrain, as lower frequency has characteristics to propagate further distances due to its longer wavelength (BBC, 2006). A comparison between 700MHz and 2,500MHz shows that 700MHz can significantly increase coverage in forested rural, hilly forested rural, suburban, and urban environments (Jong, Camire, & Rogers, 2011). The cost associated to this would include FCC license to transmit at the lower frequency and frequency specific antennas, radios, and labor.

Minor coverage improvement techniques can be made by deploying advanced antenna techniques. One of these solutions is an antenna-integrated RRH. In a typical base station, antennas are connected to radios with coaxial cables that contribute to transmission losses, which can be high depending on where the radios are installed and how long the coaxial cables are. By using an antenna-integrated RRH, the radios are built into the antenna reducing or eliminating transmission losses which can improve coverage (Kim, 2015). The cost associated to this would be new antennas and labor.

Wireless LTE coverage in the Matanuska-Susitna Borough can be improved by deploying new base stations, deployment of lower frequency spectrum, or the deployment of antenna-integrated RRH.

Summary of coverage improvement technique requirements are shown below in Table 2: Coverage improvement technique requirements.

Table 2: Coverage improvement technique requirements

Coverage Improvement Technique	Spectrum	Tower	Antenna	Radio	Supporting Infrastructure	Cost
Base Station		X	X	X	X	High
Lower Frequency	X		X	X		Medium
Antenna-Integrated RRH			X			Low

As can be seen in the table, hardware is required for all techniques. However, with deployment of lower frequency spectrum, the spectrum must be available for use which will be explored in a later section. Coverage improvement techniques will be recommended depending on the amount of coverage improvement needed and cost in a later section.

Techniques for Wireless LTE Capacity Expansion

Wireless capacity can be increased to provide higher data rates and uninterrupted service by deploying additional wireless base stations to reuse the same spectrum, using additional spectrum, or by using the spectrum more efficiently (Clarke, 2014). Deploying additional wireless sites to reuse the spectrum is very effective to increase wireless capacity in a given geographical area. The most common method is cell splitting or adding additional serving cells or base stations in the area.

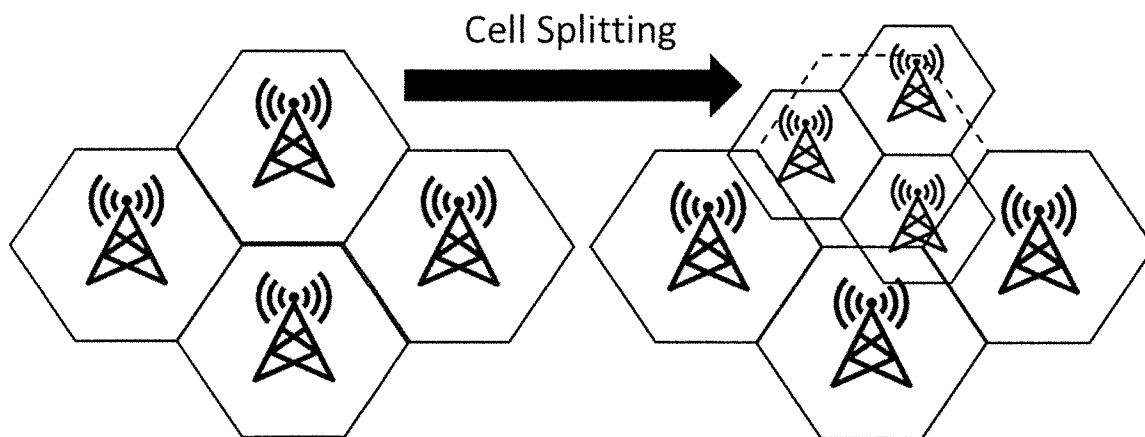


Figure 9: Illustration depicting wireless cell splitting

Effectively, the total amount of Hz in an area is increased providing more capacity. However, it can come at a very high cost as discussed previously, requiring new infrastructure including a tower, antennas, and base station equipment along with addition of supporting network infrastructure. Lower cost options exist such as microcells, picocells, and femtocells which can provide additional capacity

with a smaller coverage area. These solutions can be deployed in high traffic areas such as shopping malls, airports, or stadiums but may not be ideal for high mobility situations (Yeh, Talwar, Wu, Himayat, & Johnsson, 2011).

Additional radio frequencies, or spectrum, can also be deployed which also increases the total amount of Hz in an area without the high cost of major infrastructure. An illustration in Figure 10: Illustration of additional spectrum, shows the additional spectrum layer.

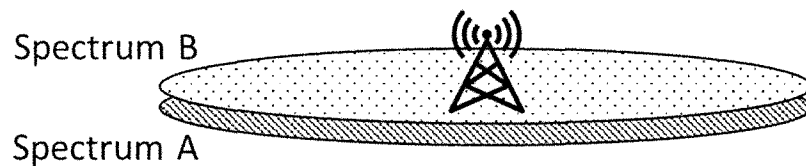


Figure 10: Illustration of additional spectrum

The illustration shows the first spectrum as spectrum A and a second spectrum as spectrum B. Since all users share the same capacity of the base station, additional spectrum would allow half of the users to be on one spectrum, the other half to be on the other spectrum, or users able to use both spectrums, essentially increasing the resources available for a given user. Without the need of major infrastructure, additional spectrum can be very effective to increase capacity. The cost associated to this would include FCC license to transmit at the frequency and frequency specific antennas, radios, and labor.

Wireless technologies also continue to improve and evolve to better utilize the spectrum more efficiently. These technologies include enhancements in LTE and LTE-Advanced which introduces concepts including carrier aggregation, spatial multiplexing using multiple-input-multiple-output (MIMO), and DL coordinated multipoint (CoMP) transmission. (Ghosh, Ratasuk, Mondal, Mangalvedhe, & Thomas, 2010). These enhancements are shown in Figure 11: Illustration of LTE-Advanced features.

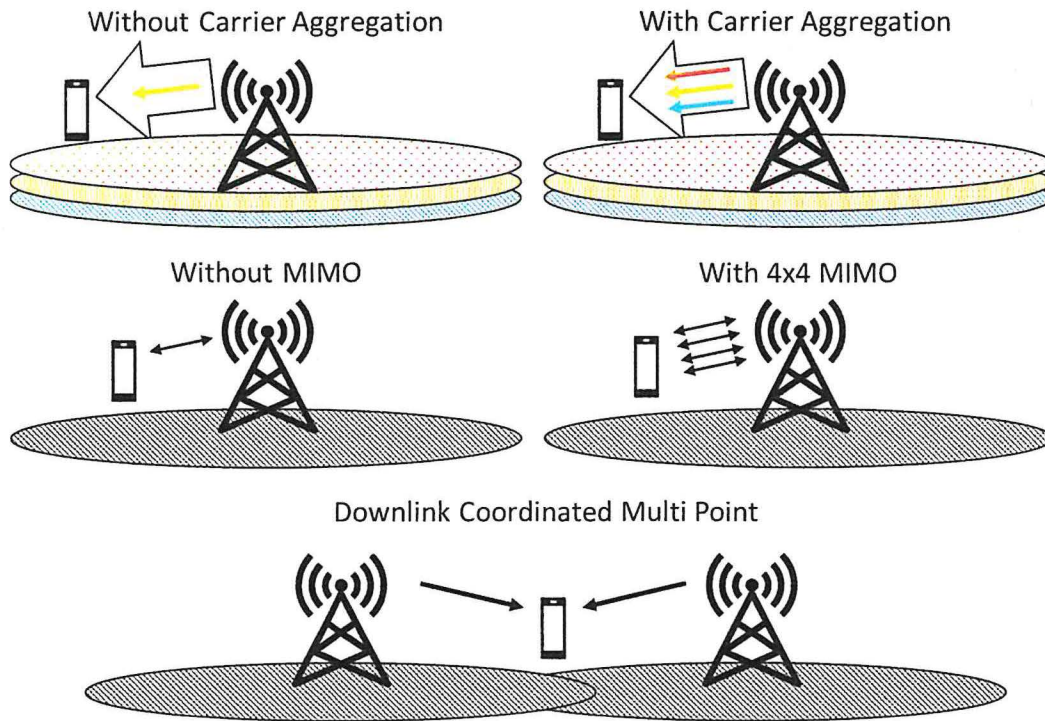


Figure 11: Illustration of LTE-Advanced features

Carrier aggregation allows devices to use multiple spectrum simultaneously, MIMO allows devices to receive multiple data streams simultaneously, and DL CoMP allows devices to receive information from multiple base stations at a given time. These enhancements can be deployed on the network but requires the user to have a device that is compatible. The cost associated to this would be minimal if supporting spectrum, radios, and antennas are already installed. If not previously installed, these will be required.

Wireless LTE capacity in the Matanuska-Susitna Borough can be improved by deploying additional base stations, deploying additional spectrum, and improvements in LTE-Advanced. Summary of capacity improvement technique requirements are shown below in Table 3: Capacity improvement technique requirements.

Table 3: Capacity improvement technique requirements

Capacity Improvement Technique	Spectrum	Tower	Antenna	Radio	Supporting Infrastructure	Cost
Base Station		X	X	X	X	High
Additional Frequency	X		X	X		Medium
LTE-Advanced	-/X		-/X	-/X		Low

However, with deploying additional spectrum, the spectrum must be available to use which will be explored in the next section. Capacity improvement techniques will be recommended depending on the amount of capacity needed.

Mobile Wireless Radio Frequency Spectrum

Mobile wireless radio frequency spectrum availability is critical for network expansion as wireless technologies must transmit and receive signals in specified frequencies. The Federal Communications Commission (FCC) allocates and regulates the radio frequency spectrum for specified use in the United States (Federal Communications Commission, n.d.). Within the radio frequency spectrum are frequency ranges allocated for mobile wireless use. The mobile wireless spectrum currently includes Cellular, Broadband Personal Communication System (PCS), Advanced Wireless System (AWS), Wireless Communications Service (WCS), 700MHz Service (SMH), and others. Each spectrum is further divided into smaller license blocks of frequencies. The following Table 4: Mobile wireless spectrum, frequency ranges, and license blocks shows the mobile wireless spectrum and frequencies used and licensed in the Matanuska-Susitna Borough.

Table 4: Mobile wireless spectrum, frequency ranges, and license blocks

Wireless Spectrum	Frequency Ranges (MHz)	Frequency License Block	Base Station Receive/Transmit Frequencies	
			Receive	Transmit
700MHz Service (SMH)	698-806	A Block	698-704	728-734
		B Block	704-710	734-740
		C Block	710-716	740-746
		D Block	716-722	
		E Block	722-728	
		Upper C Block	746-757	776-787
		Upper D Block	758-763	788-793
Cellular	824-849 and 869-894	A Block	824-835, 845-846.5	869-880, and 890-891.5
		B Block	835-845, 846.5-849	880-890, and 891.5-894
Personal Communication System (PCS)	1850-1915 and 1930-1995	A Block	1850 - 1865	1930 - 1945
		B Block	1870 - 1885	1950 - 1965
		C Block	1895 - 1910	1975 - 1990
		D Block	1865 - 1870	1945 - 1950
		E Block	1885 - 1890	1965 - 1970
		F Block	1890 - 1895	1970 - 1975
		G Block	1910 - 1915	1990 - 1995
Advanced Wireless System (AWS-1)	1710-1755 and 2110-2155, 1915-1920 and 1995-2000	A Block	1710-1720	2110-2120
		B Block	1720-1730	2120-2130
		C Block	1730-1735	2130-2135
		D Block	1735-1740	2135-2140
		E Block	1740-1745	2140-2145
		F Block	1745-1755	2145-2155
		H Block	1915-1920	1995-2000
Wireless Communications Service (WCS)	2305-2320 and 2345-2360	A Block	2305 - 2310	2350 - 2355
		B Block	2310 - 2315	2355 - 2360
		C Block	2315 - 2320	
		D Block	2345 - 2350	

Each block of frequencies is typically divided into a lower and upper frequency range, with one range being transmitted by the base stations and another being received by the base station. Each block of the spectrum is also licensed for use, which can be obtained from the FCC through an auction process or current licensee. Once licensed, the frequency block cannot be used by other entities unless authorized, expiration of license, leased, or entity ownership is acquired (Federal Communications Commission,

n.d.). Data for current licensees of the mobile wireless spectrum blocks in the Matanuska-Susitna Borough was gathered from the FCC. The wireless telecommunications company currently holds several licenses and can use mobile wireless frequency blocks in the Matanuska-Susitna Borough as shown in the following Table 5: Licensed mobile wireless spectrum in the Matanuska-Susitna Borough.

Table 5: Licensed mobile wireless spectrum in the Matanuska-Susitna Borough

Licensed Spectrum	Frequency License Blocks	Base Station Receive/Transmit Frequencies	
		Receive	Transmit
700MHz Service (SMH)	A Block	698-704 (6MHz)	728-734 (6MHz)
Personal Communication System (PCS)	A Block	1850 - 1865 (15MHz)	1930 - 1945 (15MHz)
	B Block	1870 - 1885 (15MHz)	1950 - 1965 (15MHz)
	E Block	1885 - 1890 (5MHz)	1965 - 1970 (5MHz)
Advanced Wireless System (AWS-1)	B Block	1720-1730 (10MHz)	2120-2130 (10MHz)

The wireless telecommunications company has frequency blocks available for use in SMH A block, PCS A/B/E blocks, and AWS-1 B block mobile wireless spectrum frequency blocks for a total of 102MHz, or 51MHz for transmit and 51MHz for receive. The wireless telecommunications company can reallocate, consolidate, or expand their LTE wireless network into these frequency ranges if not already being used by other mobile wireless technologies.

Methodology in Forecasting Capacity Growth

A forecasting model will be developed to determine the solution that will best meet the three year requirement of a minimum download throughput of 10Mbps. The forecast will need to provide an estimate of the contribution for capacity growth of solutions including site addition, using more spectrum, and implementation of LTE-Advanced features. Assumptions include data consumption trend continues without major shifts in and variation of trends. The forecasting model is based on the current

trend formula for data volume and throughput, in Eq. 2 and Eq. 3, from the LTE network in the Matanuska-Susitna Borough between July 2015 and September 2018.

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836 \quad (2)$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 \quad (3)$$

Using these formulas, peak data volume can be calculated by determining when data throughput is zero since they are inversely proportional. At this period, data volume should be at its peak which indicates the total capacity of the LTE network. By using Eq. 3 and solving X for when data throughput is zero, months since July 2015 can be determined.

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$0 = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$X = 50.91 \text{ Months}$$

Data throughput will be zero after 50.91 months from July 2015, which is near the end of September 2019. Peak data volume can then be calculated by solving for data volume substituting 50.91 months for X in Eq. 2.

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$\text{Data Volume} = 0.0012 \times 50.91^3 - 0.0302 \times 50.91^2 + 0.9791 \times 50.91 + 25.836$$

$$\text{Data Volume} = 155.751 \text{ TBytes}$$

The calculation shows the maximum data volume of 155.751 TBytes that can be transmitted by the LTE network in the Matanuska-Susitna Borough. Further, by dividing the peak data volume by the number of cells in the Matanuska-Susitna Borough, the average data volume per cell contribution can be determined and a forecast can be developed for capacity addition. It is assumed that around 144 cells is currently operational with a 10MHz bandwidth.

$$\text{Average Data Volume per Cell} = \frac{155.751 \text{ TBytes}}{144 \text{ cells}}$$

$$\text{Average Data Volume per Cell} = 1.0816 \text{ TBytes}$$

Average data volume per 10 MHz bandwidth is 1.0816 TBytes per cell. By applying Shannon's Theorem, a 5 MHz channel capacity would be half a 10 MHz bandwidth, resulting in 0.5408 TBytes average data volume per 5MHz cell. Data volume per cell contribution and data volume for all cells depending on the amount of bandwidth added is shown on Table 8: Data volume contribution per additional bandwidth.

Table 6: Data volume contribution per additional bandwidth

Additional Bandwidth (MHz)	Data Volume Per Cell Contribution (TBytes)	Data Volume Contribution for Bandwidth Addition on all Cells (TBytes)
5	0.5408	77.875
10	1.0816	155.751
15	1.6224	233.626
20	2.1632	311.502
25	2.7040	389.377
30	3.2448	467.253
35	3.7856	545.128

By using the data volume contribution for bandwidth addition on all cells, the total capacity of the LTE network in the Matanuska-Susitna area can be determined. An example calculation of the total data capacity of the existing base stations with a 5MHz bandwidth addition is shown in Eq. 4.

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity} \quad (4)$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 77.875 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 233.626 \text{ TBytes}$$

With an additional 5MHz bandwidth on all sites, the total data capacity is 233.626 TBytes. To determine when the capacity is forecasted to reach this, X will be solved in Eq. 2, where data volume is 233.626 TBytes.

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$233.636 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 59.860 \text{ months}$$

At 59.860 months, data volume will reach 233.636 TBytes, which is the maximum data volume capacity after bandwidth addition of 5MHz. By using 59.860 months, the data throughput can be determined using Eq. 3.

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 59.860^3 + 0.0051 \times 59.860^2 - 0.3529 \times 59.860 + 17.943$$

$$\text{Data Throughput} = -6.357 \text{ Mbps}$$

At 59.860 months, data throughput will reach -6.357 Mbps. But since bandwidth was added, this should be zero since the data volume would be at its maximum. To adjust for this, an offset of 6.357 Mbps will be applied to the trend as part of the forecasting. Throughput offsets for different bandwidth additions can be seen in Table 7: Throughput offset per additional bandwidth. Additional information and detailed calculations for other bandwidths can be found in Appendix A: Throughput offset calculations.

Table 7: Throughput offset per additional bandwidth

Bandwidth Addition (MHz)	Volume Capacity	Months since July 2015	Throughput Offset
0	155.751	50.910	0.000
5	233.626	59.860	6.357
10	311.502	66.594	12.474
15	389.377	72.111	18.483
20	467.253	76.844	24.436
25	545.128	81.020	30.355
30	623.004	84.779	36.255
35	700.879	88.211	42.142

The table shows the total volume capacity available using existing infrastructure and bandwidth addition, when the volume capacity would be reached from forecasting, and the offset that can be

applied to Eq. 3, shown in Eq. 4. Using the throughput offset from Table 7: Throughput offset per additional bandwidth, forecasting trend line equations for each additional bandwidth will be created below.

$$\text{Data Throughput (Additional Bandwidth MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + \text{Offset} \quad (5)$$

$$\text{Data Throughput(+5 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 6.357$$

$$\text{Data Throughput(+10 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 12.474$$

$$\text{Data Throughput(+15 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 18.483$$

$$\text{Data Throughput(+20 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 24.436$$

$$\text{Data Throughput(+25 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 30.355$$

$$\text{Data Throughput(+30 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 36.255$$

$$\text{Data Throughput(+35 MHz)} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 42.142$$

The trend lines are based on Eq. 5 with the offset applied for the amount of additional bandwidth.

These are plotted in Figure 12: Capacity Addition Forecasted LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps) to show forecasted throughput after bandwidth addition.

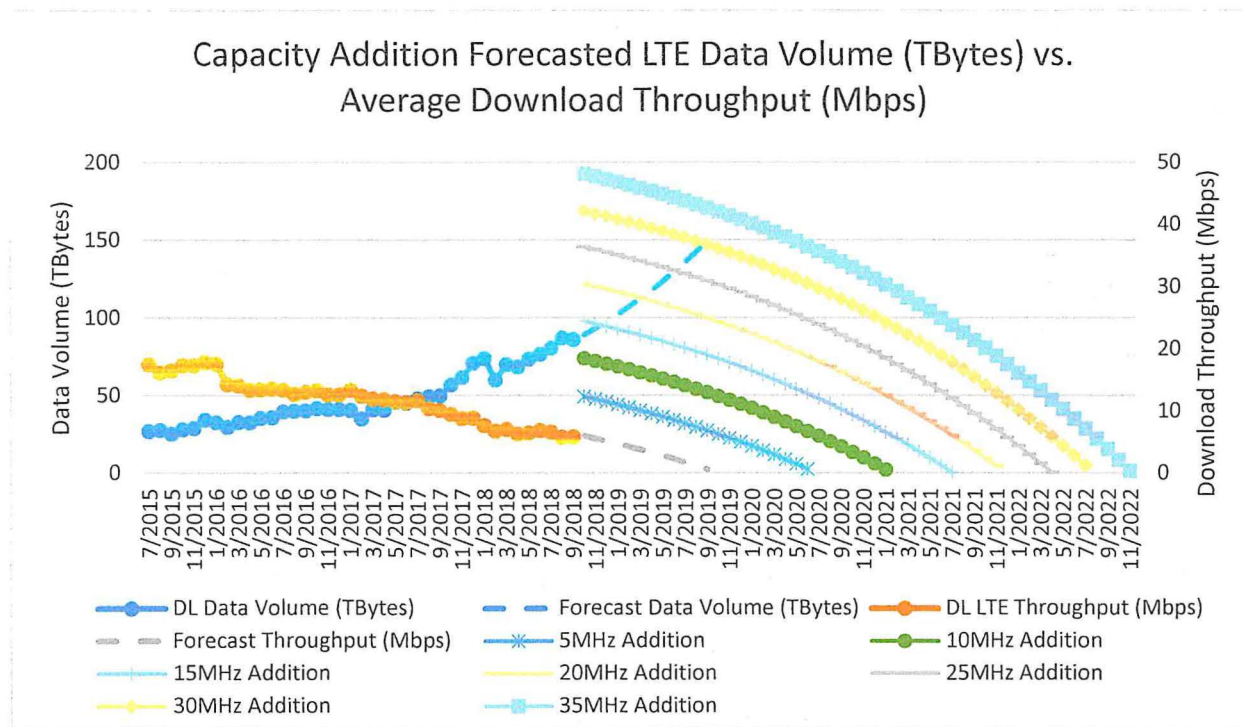


Figure 12: Capacity Addition Forecasted LTE Data Volume (TBytes) vs. Average Download Throughput (Mbps)

The graph shows historical data volume and throughput and forecasted throughput for increments of bandwidth addition. Forecasting shows that to meet the throughput requirement of a minimum download throughput of 10Mbps for the next three years that at least 25MHz of bandwidth needs to be added.

LTE Infrastructure Growth

Coverage and capacity growth are required to provide seamless coverage and improved data rates in the Matanuska-Susitna Borough to meet the requirement of a minimum of 10Mbps for users connected to the LTE network over 3 years. Coverage improvement of signal power is required to ensure subscribers can connect to LTE with uninterrupted service. Capacity improvement of bandwidth is required to increase data rates. The improvement techniques for both coverage and capacity are

combined in Table 8: Techniques to improve coverage and capacity to show each technique and if it can improve coverage, capacity, or data rates.

Table 8: Techniques to improve coverage and capacity

Technique	Coverage	Capacity	Improves Data Rate
Add Base Station	X	X	X
Add Lower Band Spectrum	X	X	X
Use Antenna-Integrated RRH	X		X
Add Spectrum		X	X
LTE-Advanced			X

The table shows that by adding additional base stations and lower band spectrum can improve both coverage and capacity. Other techniques may only improve one or the other. Requirements for techniques are shown in Table 9: Technique and requirements.

Table 9: Technique and requirements

Technique	Spectrum	Tower	Antenna	Radio	Supporting Infrastructure	Cost
Base Station		X	X	X	X	High
Additional Frequency	X		X	X		Medium
Antenna-Integrated RRH			X			Low
LTE-Advanced	-/X		-/X	-/X		Low

The table shows that requirements of each technique with cost. Recommendations will be made to achieve both coverage and capacity improvements with the least requirements and cost.

Coverage and Capacity Improvement Recommendations

The wireless telecommunications company's requirement to provide seamless LTE coverage in the Matanuska-Susitna Borough can be achieved by applying all the techniques previously discussed including new base stations, adding lower band spectrum, and using antenna-integrated RRH. Large areas of poor signal power would be candidates for new sites and small areas of poor signal power would be candidates for lower band spectrum, both of which would use antenna-integrated RRH. Figure

13: Recommended new base station locations in the Matanuska-Susitna Borough shows areas of recommended base station additions.

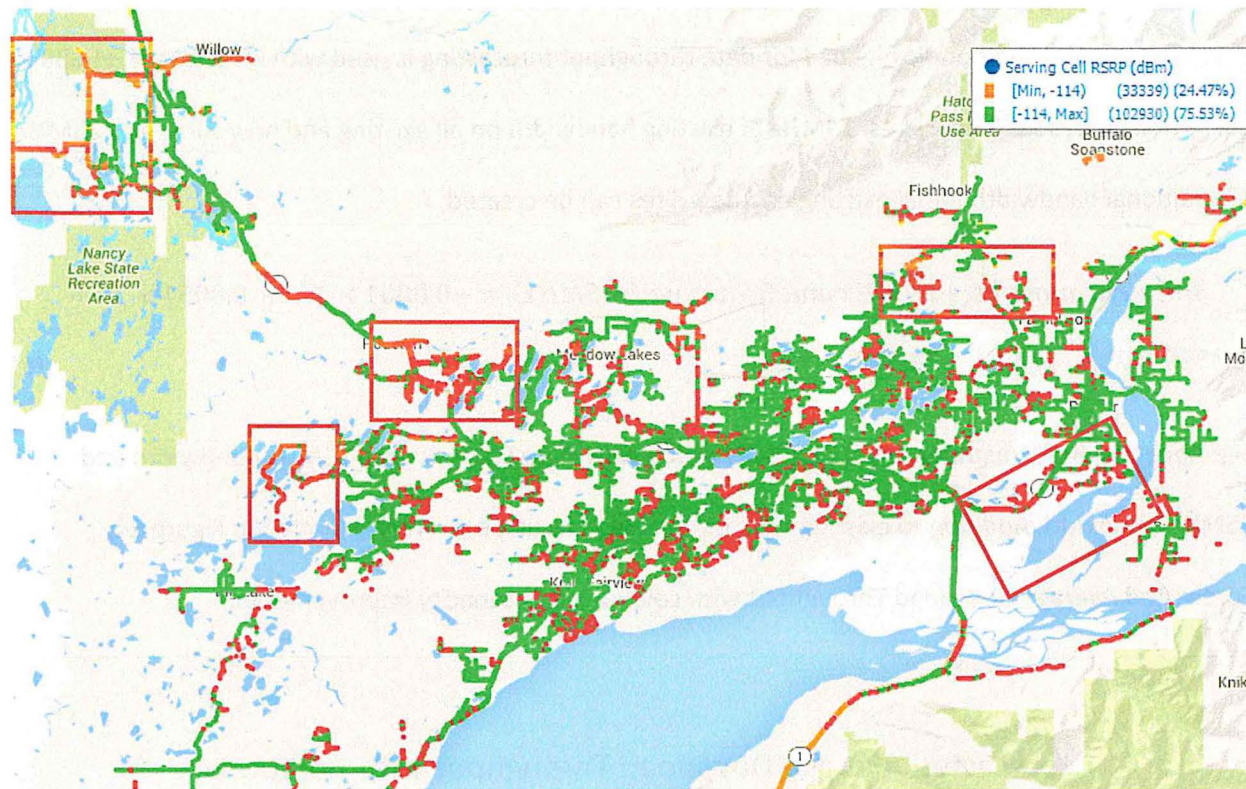


Figure 13: Recommended new base station locations in the Matanuska-Susitna Borough

The five boxed areas show large areas of poor signal power which are recommended for new base stations. Smaller areas with poor signal power are scattered throughout and can be addressed using 700MHz spectrum on all new and existing base stations with antenna-integrated RRH. These recommendations will provide seamless LTE coverage and improve data rates throughout the Matanuska-Susitna Borough.

The wireless telecommunications company's requirement to provide a minimum of 10Mbps over the next three years will require at least 20MHz of additional bandwidth in addition to the

coverage improvement recommendation of 5 new base stations and 700MHz spectrum. With additional base stations, 10MHz of existing bandwidth, 5MHz bandwidth of 700MHz, and 20MHz of 1900MHz spectrum for a total of 25MHz of additional spectrum on all base stations, data volume capacity will increase to 601.910 TBytes per month allowing data rates to be above 10Mbps until December 2021. Using the forecast methodology, Eq. 4 for data throughput forecasting is used with an offset of 34.658 in Eq. 5, which includes 5 new sites, 10MHz of existing bandwidth on all existing and new sites, and 25MHz of additional bandwidth for all existing and new sites can be created.

$$\text{Data Throughput}(+25 \text{ MHz and 5 Sites with 35MHz}) = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 + 34.658 \quad (5)$$

See Appendix B: Throughput offset calculation for 5 New Base Stations with 35MHz Bandwidth and 25MHz Bandwidth Addition to existing sites for detailed calculations. This is plotted in Figure 14:

Forecasted Average Download Throughput with coverage and capacity improvements.

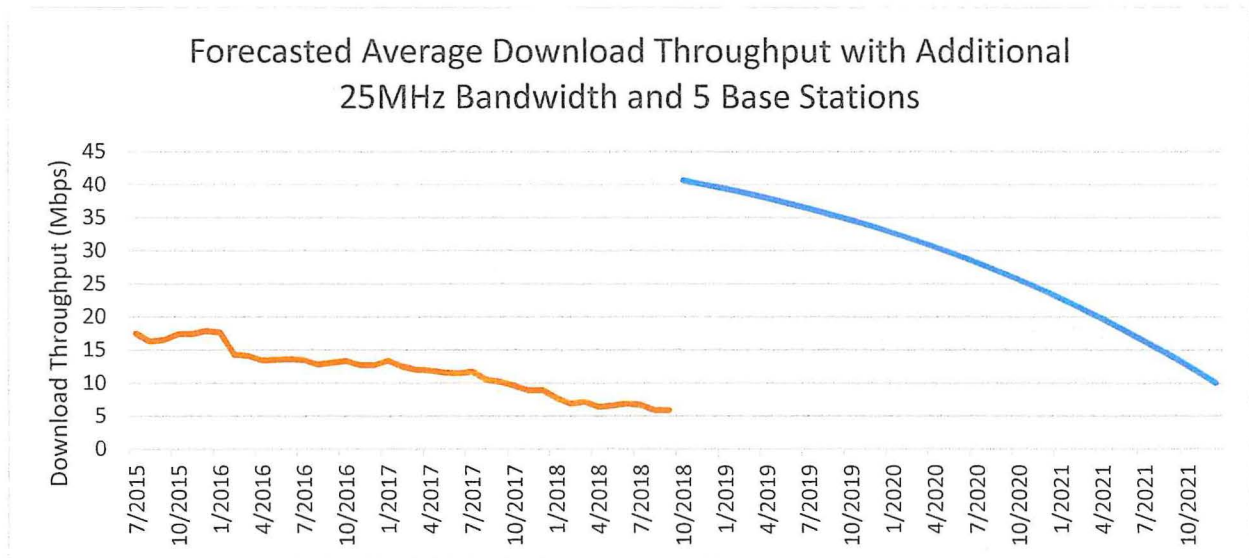


Figure 14: Forecasted Average Download Throughput with coverage and capacity improvements

With the addition of 5 base stations and 35MHz of total bandwidth on all new and existing sites, average download throughput can reach up to 40Mbps at the end of 2018 and reduces to 10Mbps at the end of 2021. However, this can be done incrementally as shown in Figure 15: Forecasted average download throughput with coverage and capacity improvements, incremental 5MHz addition.

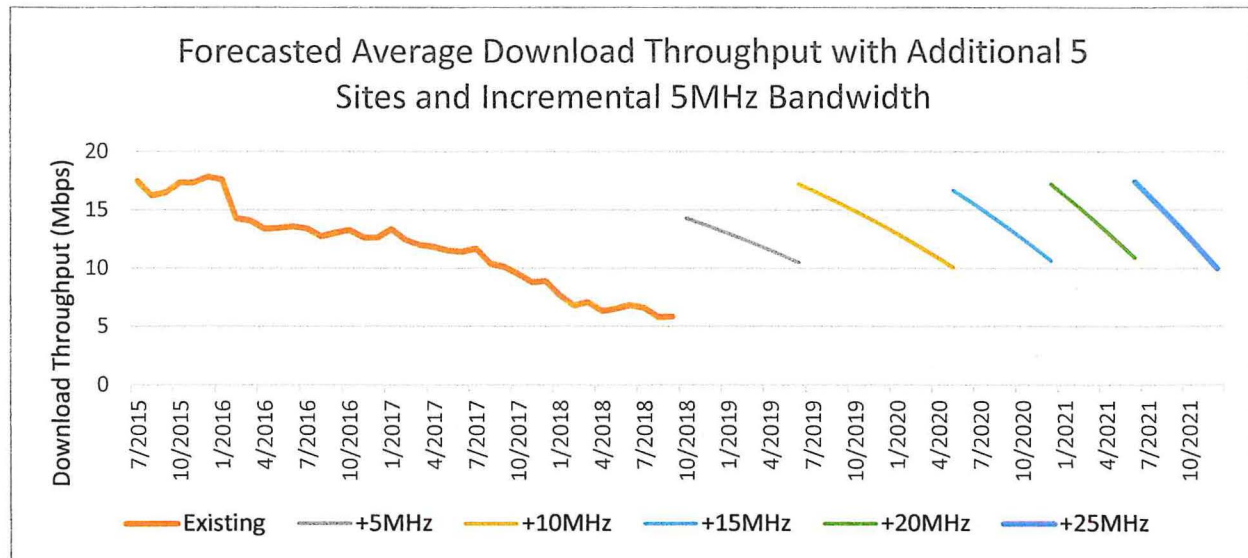


Figure 16: Forecasted average download throughput with coverage and capacity improvements, incremental 5MHz addition

Bandwidth addition of 5MHz increments would need to be completed prior to October 2018, July 2019, June 2020, January 2021, and July 2021. The recommendation of 5 new sites and a total of 35MHz bandwidth on all sites will allow the wireless telecommunications company to meet and exceed the requirement of minimum download throughput of 10Mbps for the next three years.

Conclusion

Wireless LTE infrastructure is required to meet the requirements of seamless coverage and a minimum of 10Mbps over the next three years. Recommendations to improve coverage and capacity are as follows:

- Add 5 Base Stations with 10MHz of AWS
- Add 5MHz 700MHz spectrum to all base stations
 - Use antenna-integrated RRH
 - Enable LTE-Advanced Carrier Aggregation and 4x4 MIMO
- Add 20MHz 1900MHz spectrum to all base stations
 - Use antenna-integrated RRH
 - Enable LTE-Advanced Carrier Aggregation and 4x4 MIMO

The addition of 5 base stations and 5MHz 700MHz using antenna-integrated RRH's are required to be completed prior to June of 2019. Additional 20MHz of 1900MHz spectrum can be performed in stages with an initial 5MHz completed prior to June of 2019, additional 15MHz can be completed afterwards. This is to meet or exceed the minimum download throughput of 10Mbps and seamless coverage throughout the Matanuska-Susitna Borough.

Appendices

Appendix A: Throughput offset calculations

0MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 0 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$155.751 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 50.910 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 50.910^3 + 0.0051 \times 50.910^2 - 0.3529 \times 50.910 + 17.943$$

$$\text{Data Throughput} = 0 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 0 \text{ Mbps}$$

5MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 77.875 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 233.626 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$233.636 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 59.860 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 59.860^3 + 0.0051 \times 59.860^2 - 0.3529 \times 59.860 + 17.943$$

$$\text{Data Throughput} = -6.357 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 6.357 \text{ Mbps}$$

10MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 155.751 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 311.502 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$311.502 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 66.594 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 66.594^3 + 0.0051 \times 66.594^2 - 0.3529 \times 66.594 + 17.943$$

$$\text{Data Throughput} = -12.474 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 12.474 \text{ Mbps}$$

15MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 233.626 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 389.377 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$389.377 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 72.111 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 72.111^3 + 0.0051 \times 72.111^2 - 0.3529 \times 72.111 + 17.943$$

$$\text{Data Throughput} = -18.483 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 18.483 \text{ Mbps}$$

20MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 311.502 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 467.253 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$467.253 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 76.844 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 76.844^3 + 0.0051 \times 76.844^2 - 0.3529 \times 76.844 + 17.943$$

$$\text{Data Throughput} = -24.436 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 24.436 \text{ Mbps}$$

25MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 389.377 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 545.128 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$545.128 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 81.020 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 81.020^3 + 0.0051 \times 81.020^2 - 0.3529 \times 81.020 + 17.943$$

$$\text{Data Throughput} = -30.355 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 30.355 \text{ Mbps}$$

30MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 467.253 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 623.004 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$623.004 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 84.779 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 84.779^3 + 0.0051 \times 84.779^2 - 0.3529 \times 84.779 + 17.943$$

$$\text{Data Throughput} = -36.255 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 36.255 \text{ Mbps}$$

35MHz Bandwidth Addition

$$\text{Data Capacity After BW Addition} = \text{Current Data Capacity} + \text{Additional Data Capacity}$$

$$\text{Data Capacity After BW Addition} = 155.751 \text{ TBytes} + 545.128 \text{ TBytes}$$

$$\text{Data Capacity After BW Addition} = 700.879 \text{ TBytes}$$

$$\text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$700.879 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836$$

$$X = 88.211 \text{ months}$$

$$\text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943$$

$$\text{Data Throughput} = -0.0001 \times 88.211^3 + 0.0051 \times 88.211^2 - 0.3529 \times 88.211 + 17.943$$

$$\text{Data Throughput} = -42.142 \text{ Mbps}$$

$$\text{Data Throughput Offset} = 42.142 \text{ Mbps}$$

Appendix B: Throughput offset calculation for 5 New Base Stations with 35MHz Bandwidth and 25MHz

Bandwidth Addition to existing sites

$$\begin{aligned} & \text{Total Number of Cells with 5 New Base Stations} \\ & = 144 \text{ Existing Cells} + 5 \text{ New Base Stations} * 3 \text{ Cell} \end{aligned}$$

$$\text{Total Number of Cells with 5 New Base Stations} = 159 \text{ Total Cells}$$

$$\begin{aligned} & \text{Total Data Capacity After Site and BW Addition} \\ & = 159 \text{ Total Cells} * 3.7856 \text{ TBytes contribution for 35MHz} \end{aligned}$$

$$\text{Total Data Capacity After Site and BW Addition} = 601.910 \text{ TBytes}$$

$$\begin{aligned} & \text{Data Volume} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836 \\ & 601.910 \text{ TBytes} = 0.0012 \times X^3 - 0.0302 \times X^2 + 0.9791 \times X + 25.836 \\ & X = 83.797 \text{ months} \end{aligned}$$

$$\begin{aligned} & \text{Data Throughput} = -0.0001 \times X^3 + 0.0051 \times X^2 - 0.3529 \times X + 17.943 \\ & \text{Data Throughput} = -0.0001 \times 83.797^3 + 0.0051 \times 83.797^2 - 0.3529 \times 83.797 + 17.943 \\ & \text{Data Throughput} = -34.658 \text{ Mbps} \\ & \text{Data Throughput Offset} = 34.658 \text{ Mbps} \end{aligned}$$

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